The Space Power Grid: Synergy Between Space, Energy and Security Policies

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Abstract - **The dream of abundant solar-powered electricity from Space can be realized through global synergy between renewable energy, climate control and space development initiatives. A 3-phase plan is linked to the policy approaches needed to implement it. The 17-year initial phase will use a constellation of low/mid earth orbit satellites exchanging beamed power between 100 plants. Larger satellites with high-intensity converters, will replace the aging first set, receiving focused light from ultralight collectors in a scalable path to space solar power. European initiatives for a DC grid to integrate space and terrestrial solar power provide policy guidance. While technical challenges remain, the SPG integrates terrestrial systems at all size scales from utilities to household micro renewable energy systems.**

Keywords **– Space solar power, renewable energy, climate policy, global warming, infrastructure, power grid, millimeter waves.**

I. INTRODUCTION

The dream of Space Solar Power (SSP)[1] is that abundant, clean, steady electric power can be generated "24/365" in Space, and conveyed down to Earth. Many concepts have been proposed [2,3,4,5] to harvest SSP on a massive scale. Most are to beam the power down from large (>100 sq.km) converters at geo stationary earth orbit (GEO), 36,000km above the equator. Large beam divergence, mass needed at GEO, immense ground infrastructure and limited coverage beyond 30 degree latitude, make this a non-starter. The cost to first revenue is beyond hope.

The Space Power Grid (SPG) approach [6,7,8] seeks to break through this problem with an evolutionary, scalable approach to SSP within 25 to 30 years from project start, with a viable business plan and minimal costs to taxpayers. This paper deals with the interplay of technology, economics, global relations and national public policy involved in making this concept come to fruition.

Why SSP? Why has it Remained a Dream?

Table 1 compares the problems and advantages of space-based versus terrestrial solar power generation. The two great advantages are (1) that steady power is generated round the clock because the Sun is not obscured, and (2) as the scale increases, SSP becomes cheaper, with no upper limit on the amount of power that can be captured. The data in the first row [9] show that even if the conversion to and from beamed energy is only 20% as efficient as terrestrial transmission, SSP is more efficient than ground-based solar power. Add the fact that conversion from solar to electric power can be 2 to 3 times as efficient in space because of better thermodynamics and higher-output, longer-lasting cells. Terrestrial primary energy consumption by human activity is below 0.1% of the total solar energy falling on Earth, and conceivably, lenses in solar orbit could collect solar radiation from far outside the Earth's capture area. So SSP is a long-term clean energy solution. The other issues make it hard to justify commercial investment in SSP for nearer-term impact.

Table 1: Comparison of space vs. ground based solar power

Feature	SSP	Ground-based solar power
Steady generation	24 hour, year-round. ~12,000KWh/yr	Daily /seasonal/ weather fluctuations. Average ~900 to 2,300 KWh/yr
Waste heat	Dissipated in Space	Released on Earth
Transmission efficiency	Low, weather-dependent	High, independent of weather (see above)
Receiver/distributor Infrastructure size	Massive for GEO sats due to beam width, for any power level	Scalable from rooftop to Sahara size
Generator size	Massive for GEO sats.	Scalable
Installation cost per watt	Very high due to GEO launch cost	Moderate

At GEO, a satellite revolves around Earth's axis once every 24 hours. Thus, it appears to be stationary above a point on Earth's Equator. Concepts from the 1960s[1] called for very large solar-cell arrays to be built in GEO, beaming electric power down as microwaves to large receivers on Earth. Frequencies well below 10 billion cycles per second (10GHz) are generally not absorbed by the atmosphere whether dry or wet, and hence this regime was selected for power transmission. NASA and others have conducted numerous studies on SSP[2-5,10,11,12,13], but always focused on GEO-based collector/converter/beaming systems. These choices have two consequences:

1) The cost of launching objects to GEO is on the order of \$12000 to \$24000 per kilogram.
2) The minimum diameter of the beam is on the order of several kilometers, for this frequency range and distance, regardless of the power transmitted.

The result of the studies is always the same: it costs far too much to launch the solar cell arrays and converters to GEO, and to assemble the stations. If the number of ground stations is minimized, the distribution infrastructure becomes enormous. Only massive government spending can be visualized as a funding source, and even that is outside the realm of reality. The figure of “$300B to first power” is dangled in many reports. This was based on the estimate of $100 per pound to low earth orbit, used as advertisement for the Space Shuttle when it was sold to Congress in the 1970s. The reality today is over $14,000 per pound to Low Earth Orbit using the Shuttle, and more to GEO. For these reasons, SSP has remained a dream. We note that the real issue is lack of an evolutionary path to get the SSP system through initial infrastructure development, to a critical size where its true potential becomes self-sustaining.

II. THE NEW WINDOW OF OPPORTUNITY: RENEWABLE POWER AND CLIMATE CONTROL IMPERATIVES

Briefly, our Space Power Grid (SPG) approach is a 3-stage process to bring about full SSP, through synergy with the terrestrial Renewable Energy and Climate Control initiatives. Today rising energy demand is driving construction of renewable power plants around the world. The global imperative to control emissions of heat and Greenhouse Gases (GHG) into the atmosphere provides additional opportunities. Issues that arise from these areas are summarized below.

a. Baseload Qualification for Wind and Solar Power

The market value of electric power is much higher if the supplier can guarantee a certain level of power generation, and meet sudden peaks in demand. Such power qualifies for the status of “baseload power”[14]. Solar, wind and tidal plants are fundamentally inhibited by 3 problems:

1. The best places to extract renewable power are high-altitude and remote deserts, plateau edges, mountain slopes, glacier bases and coastlines. Much of the planet has either no power grid or low-capacity, outdated power grids, and hence transmission costs are high. On the other hand, large temporal fluctuations in demand, and price occur mainly in the big cities and industrial areas.
2. All solar and wind plants are handicapped by large fluctuations or day-night / seasonal cycles and weather. Many use fossil-burning, GHG-emitting auxiliary generators to qualify for baseload status, but this means having to install twice the capacity that the plant can sell.
3. The installed cost per unit power is high for solar and wind plants, even without having to install inefficient auxiliary generators and associated infrastructure.

b. Climate Change and the Carbon Market

The confluence of the energy crunch and climate change concerns, bring an unusual opportunity. For the first time, there is a source of significant revenue and international mandate associated with replacing fossil-generated power.

III. THE SPACE POWER GRID APPROACH

In Phase 1, no power is generated in Space. Instead, Space is used[3] as the avenue to exchange power generated by renewable energy plants located around the world. A small constellation of satellites, in 2000 kilometer high orbits (Low to Medium Earth Orbit), act as waveguides, beaming millimeter-wave power from plants during peak production, to their counterparts where the sun is not shining or the wind not blowing as depicted in Figure 1.

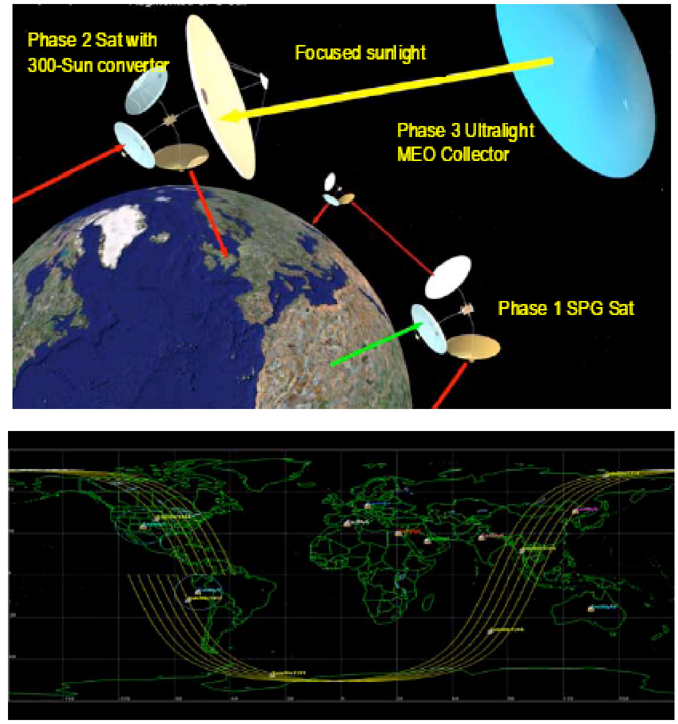

Figure 1: Above: SPG: 3-phase approach. Satellites shown hugely out of scale. In Phase 1 (17 years, power exchange between renewable plants and markets funds system growth. Phase 2 adds 300-sun converters. Phase 3 adds ultralight collectors. Below: SPG Startup with the Afternoon Sun Scenario (Ref.[5]). 80 mins access per 24 hrs. Each sat executes 23 orbits in 48 hours.

The SPG opens up global markets to these new plants, including islands and remote areas where electric power commands much higher prices than it does in developed areas served by the terrestrial power grid. Thus, even the low efficiency of beamed transmission is justified by the access to places where high prices are received.

Phased array transmitters enable beaming to moving satellites. We suggested a mix of polar "sun-synchronous" (passes same location on earth at the same time each day, usually several orbits a day, see Figure 2), and near-equatorial orbits. Transmission would occur in bursts lasting 2 to 15 minutes to each satellite from a ground station [15]. As the system expands, this becomes continuous. The satellites themselves are essentially waveguides with heat engines converting waste power to high-frequency beamed power sold to other satellites at profitable prices, or co-located with mobile communication / metereological platforms.

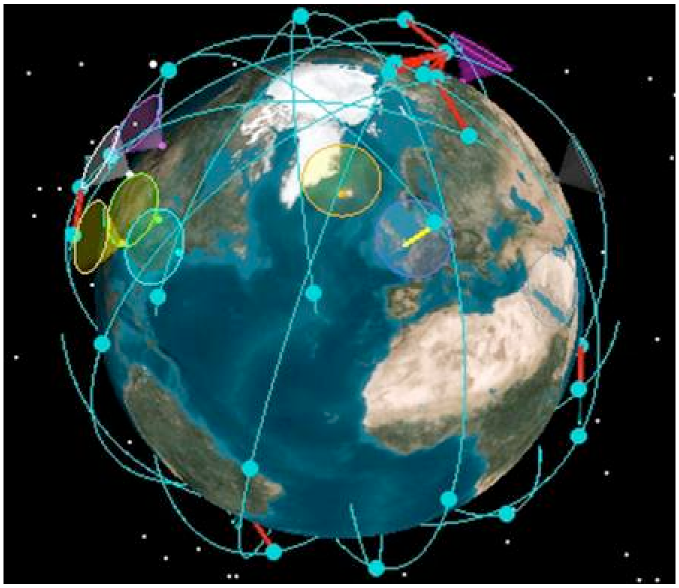

Figure 2: Sun-synchronous low/mid earth orbits provide global coverage.

Method of Analysis

We have developed a calculation model linking the choice of frequency to the lifetime economic implications of the system. This lifetime analysis is used to narrow the choices of various parameters to find viable regimes. Time to break even at given Internal (or "Project") Rate of Return, is used as the metric. With SPG, the receivers can be located anywhere, but the natural choice is co-located with the generating plants, and at retail distribution centers. With a choice of many plants and satellites, SPG beams can avoid the weather. Data show [16] that periods of rain are limited to a few hours a year at the best locations for power generation. So there is no need to limit the atmospheric transmission window to below 10 GHz. The effect of the frequency choice can be seen below. Antenna size and orbit height are related through the formula for complete beam capture:

$$D_r D_t / \lambda S = 2.44$$

where D is effective diameter, subscripts t and r denote transmitter and receiver, λ is wavelength and S is the distance between the transmitter and receiver. With frequency f in GigaHertz, and dimensions in metres, the relation is:

$$\frac{D_r D_t}{S} = \frac{0.732}{f}$$

The 45-degree transmission distance is taken as the design value for S. When the frequency is below 10 GHz, the diameters of the transmitter and receiver are very large. A compromise is typically to capture only 80% of the beam. This in itself more than negates the advantage of achieving better than 90% transmission efficiency through the atmosphere. On the other hand, if the frequency is moved to the 200-220GHz atmospheric transmission window, the antenna is small enough that more than 99% beam capture can be achieved, and the transmission efficiency through dry air approaches 80%. Transmission through rain will be impractical in this regime, however, this is not a killer issue given the multiple choices of receiver location possible, and the low probability of rain at preferred generator locations. For example [12], for our choice of 200GHz and a 50m antenna in space, the ground antenna would have 200m diameter. For inter-satellite beaming, two satellites separated by 45 degrees in circular orbit give a transmission distance of 6410 kilometers. Each antenna is 146 meters in effective diameter, and each craft has two such antennae in addition to the ground beaming antenna. The major impact, however, is in the reduced satellite mass with the choice of high frequency. Satellite mass has a strong influence on system costs, and even with optimistic projections of the mass per unit area needed to build antennae, it is clearly impractical to build satellites where the frequency choice is much below 100GHz.

The SPG can generate useful revenue at a minimum size of 20 satellites and 12 plants. In Ref. [5] we showed that with 200GHz transmission, and with a 30% end-to-end transmission of the power, SPG Phase 1 *with no power generated in space* can be competitive with terrestrial power options, in places where the power fetches high prices due to peak demand, or lack of generation and transmission (e.g., islands, and prime time in big cities). This assumes that power generation has the same efficiency as any other power, so the 30% should be compared to the 94% transmission that the US grid claims. If this can be achieved, then system costs can be recovered in about 17 years. By that time the next phase can start, where large ultralight reflectors in GEO (Phase 3) focus sunlight down to 300-Sun solar-electric converters placed on the Phase 2 satellites that will replace the original waveguide satellites. The cost of delivered power will then decrease substantially. The road to keep increasing terrestrial primary electric supply (or replacing today's GHG-emitting fossil-based plants) will be open. Phase 3 then allows for expansion until the constellation in L/MEO reaches saturation. To double terrestrial primary energy availability, some 300 square kilometers of ultralight reflectors will be needed in high orbits. In summary, our Space Power Grid concept addresses the issues of Table 1, as shown in Table 2 below:

Table 2: Features of the Space Power Grid approach to space solar power

Feature	SPG
Steady generation	Constellation of satellites ensures that some face the Sun at all times, without having to be in GEO.
Transmission efficiency	Weather dependence eliminated by choice of atmospheric transmission paths.
Infrastructure size	Small due to lower orbit (2000km) and high frequency (200 GHz)
Generator	Scalable
Installed cost per watt	Moderate.
Infrastructure investment	Justifiable solely based on terrestrial power generation, and expands to capture space solar power after break-even.

Technology Challenges

The SPG is not without major technical hurdles. The foremost is the efficiency of generating and converting to and from the 200 GHz regime. Breakthroughs in millimeter wave electronics have enabled as much as 70% efficiency using microcircuit chips that can be mass manufactured to produce arrays of the required power level. The technology of phased array transmitters is fairly advanced, and enables precise beaming to moving satellites. Switching technology in the 200-300GHz regime has advanced, driven by defense applications. Thermal management systems capable of handling megawatt power levels are a challenge, but turbine-based approaches have been developed. The status of the technology is such that it is time to line up the public policy.

IV. ECONOMICS OF THE SPACE POWER GRID

The business case is based on 4 features:

1) SPG allows solar and wind power plants to achieve baseload provider status, and compete for premium prices by exchanging power with plants anywhere. Fossil power use is reduced by enabling renewable plants in remote locations including islands, and by reducing the need for backup power generation. Carbon credits provide a small continuing revenue stream, but also qualifies the system for a much larger initial public investment.
2) As the constellation grows, antenna size is reduced, eliminating the need for major assembly in orbit, and thus minimizing development and launch costs. Constellation growth is matched to the commissioning of renewable power plants, which can be located in ideal locations without need for market proximity.
3) Use of a constellation as a power grid minimizes the impact of weather by providing transmission alternatives.
4) Revenue growth occurs early with a few satellites and participating plants, eliminating the huge cost-to-first-power drawback of GEO-based concepts.

Detailed calculations of Net Present Value and the Internal Rate of Return (IRR) needed for breakeven in a set number of years, have shown (Ref. 15) that a power cost of 30 cents per KWh can be achieved, breaking even with reasonable IRR of 8% within 23 years from project start, given the first satellite launch in year 6. This is with zero government funding. With about $6B invested during the development phase, this can be achieved even if system efficiency does not improve much from what is possible today. The economics of Carbon Credits and control of global Climate Change improve the viability of the SPG, while the SPG eliminates the need for megameters of concrete and metal transmission grids that take an enormous amount of energy to develop.

V. ESTABLISHING SYSTEM SIZE AND POWER LEVEL

In Ref. [17] we explored the minimum size of the Phase 1 system, required to make it self-sustaining regardless of the implementation of Phases 2 and 3. Such a system would require the motivations that drive Space agencies worldwide, and hence must have SSP as an ultimate goal. The exercise established the cost of power, the required end-to-end efficiency, the relations to satellite number, and the minimum level of power transacted per satellite to make the system viable. Development and production costs were estimated using the NASA-Air force NAFCOM cost models[18] with an 85 percent Wright Learning assumed. Launch costs were estimated using an interpolated form of the lower-bound estimates from the FUTRON launch cost survey [19] of 2004, based on data up to 2000. The minimum power level was shown to be around 60 MW per satellite. At this level, the system would start functioning with as few as six satellites and 12 power stations, but was then expanded to a size of over 100 satellites and stations. The number of stations can be considerably larger than the number of satellites, when intermittency of transmission and weather issues are taken into account, and the cost of installing beaming and receiving facilities on a ground station are small in this architecture. Results are shown in Table 3.

Table 3: Present System Parameters

Parameter	Value
Satellite Power Level:	60MW
Satellite mass:	4510 kg
Launch cost to 2000 km high circular orbit:	$ 19.8M
Development cost for system:	$ 330M
Production cost for 1st 36 satellites:	$1370M
Ground facilities development cost:	$1000M
Per satellite annual mission operations and data analysis cost:	$2.75M
Ground station power level	$55MW
Cost of production of power	4 cents per KWH
End-to-end efficiency of beaming power grid	0.3
Sales price at delivery point	30 cents per KWH
Gross margin	5 cents per KWH
SPG share of gross margin:	4.5 cents per KWH

VI. POLICY ISSUES

The European Union's Trans-Mediterranean Connection for Concentrated Solar Power (TRANS-CP) [20,21,22] proposes to set up a large, high-voltage DC grid connecting solar plants in the Sahara desert across the Mediterranean and English Channel to North Atlantic / North Sea British/German / Dutch wind generators. The extreme logistical, environmental and political costs of such a project, show the level of urgency in building a way to exchange power between different clean renewable sources, most of which are naturally suited to generate DC power rather than single-frequency AC power. In this paper we use the planning for the TRANS-CP for guidance in the policy needs for SPG.

Expert surveys in Ref. [20] found that a majority agreed that massive solar power is an excellent long-term option, but few felt that it would happen in the short term, and hence few saw a need to assign a high priority for action towards this goal.

However, the number of experts who now see solar power as a long-term need and option, has itself increased substantially in recent years. This discrepancy between awareness and action, and other aspects of policy and financing to enable renewable power generation, are laid out in Table 4.

Table 4: Policy to assist development of renewable energy. Based on [20]

Policy Issues	Financial Benefits
Discrepancy of Awareness and Action Feed-in Tariffs to foster innovation. Renewable Portfolio Standards (RPS) Competitive Bidding for RPS capacity allotments Net metering. Renewable Energy Certificates Green Power Purchasing Kyoto Instruments (carbon credits)	Grants to producers and consumers Low-interest loans Tax exemptions, rebates Depreciation Demand guarantees, price controls Market access Land access Environmental licenses Portfolio mandate

Feed-in laws substantially reduce the risk of commercial investment in renewable energies. For instance, whereas the required IRR for conventional power plants is only 6.7%, that on renewables is on the order of 15% due to the high technical and market risks.The feed-in tariff law reduces the uncertainty about power sales rate. Many nations have set Renewable Portfolio Standards (RPS) for their power utilities. For instance, Sweden sets an annual increase, with 150% penalties for not achieving the standards. Poland aims for 7.5% renewables by 2010. Net metering is instituted in several countries to enable local generation of renewable power. Here the customer is allowed to feed power back into the grid, and only pay for the net power used. The utility/grid is mandated to accept the fed-back power. RPS drives competitive Bidding for capacity allotments and provides additional price support to install renewable power plants.In addition to the internationally traded Carbon Credits set up by the Kyoto Protocol for reducing GHG emissions, nations also have instituted Renewable Energy Certificates and Green Power Purchasing.

Other mechanisms to support the development of renewable resources include direct capital investment subsidies or rebates, tax incentives and credits, sales tax and VAT exemptions, direct production payments or tax credits, and direct public investment or financing.

Ref. [20] identifies basic requirements for the political frameset needed for such a project: the participants must bring supplementing and not competing capacities, and they must have common and not conflicting goals. Incentives must be provided for a quick start and for long-term investment security. They recommended a Euro-Mediterranean Free Trade Area for Renewable Energies (RE-EMFTA) including free cross-border transfer of renewable energy products and technology, and appropriate subsidies for renewable energy on the same level or better than those given for competing fossil or nuclear power industry. The entities within the RE-EMFTA would also implement the policy instruments mentioned in Table 4, and establish a common Fund and Panel guaranteeing power purchase agreements and ensuring reasonable tariffs that enable achievement of targets.

In the US, projects such as the large wind farms in the Dakotas [23] rely on the future expected rise in price of Clean Energy credits as a venture capital business case to build wind turbine farms. Other such initiatives are expected as the new Administration opens US acceptance and adaptation of policies adopted in other countries.

SPECIAL POLICY FEATURES OF THE SPACE POWER GRID

1. Global Collaboration Model

Such a system involving global power exchange obviously requires global collaboration. It spans many of the issues in building Space infrastructure, and international collaboration for ground infrastructure and energy trading. ROI large enough to attract private capital is not realistic because of the large risk. Public financing is also needed to ensure serious intent on the part of governments to complete the project.

The SPG involves placing a substantial number of satellites into low/mid earth orbit, and several large ultralight collectors into high orbits. There will be powerful beams of energy criss-crossing between these. Cooperative regulation could be modeled after the various UN agreements that allot orbit sectors and frequency bandwidth to nations to enable the communication satellites, the GPS, Galileo and Glonass global positioning systems. A global solar power grid in Space should meet with support from all the spacefaring nations, and from most non-spacefaring nations. Already, apart from the US and Europe, Japan, which has few fossil power resources, has a very strong program[24,25] for space solar power. China has been tapped by the European Union for participation in a power grid. Russia, China, Africa and Australia have vast undeveloped areas that are suitable for renewable power generation but lack terrestrial power grids, while the many island nations of the world would benefit from beamed power as a replacement for fossil power. India, with a growing space program, has already invested heavily in microwave infrastructure for communications, and should be amenable to converting some of that to power beaming purposes. With the next round of the Climate Control global agreement due in 2013, consensus appears to have emerged on the issues confronting nations, as well as the possibility of concerted global action. This generates a climate ripe for undertaking the massive collaborative effort that can lead to true energy independence.

In Ref [26] we proposed a global public-private Consortium, partially based on the model for the European Space Agency, where member nations and private corporations collaborate to reduce risk, make low-interest long-term funding available, and organize the construction of major Space infrastructure. This set up is also shown to open a path towards resolving some of the most vexing obstacles in space resource utilization, arising from current Space Law. On a national level, moving towards the Space Power Grid approach requires some fundamental realignments that synergize the Space and Energy enterprises with the environmental / Climate Change control movement. In the United States, this requires and alignment of NASA and the Department of Energy, probably through an agency such as "ARPA-E".

2. Transmission infrastructure on the ground

The Space Power Grid reduces the ground transmission infrastructure needs of new renewable energy plants substantially. It eliminates the need to lay high power transmission lines across pristine and often hostile terrain and across deep water. In this respect, it avoids the strong opposition to building large transmission grids, cited as a major issue in the European DC grid plans.

3. Public acceptance of beamed power from Space

In direct contrast, power beaming poses unknown fears to the population. Microwave beams conjure images of Death Rays, passengers getting cooked inside airplanes and birds in the sky, cities being burned, and cancer incidence rising. Strong electromagnetic beams may induce atmospheric and terrestrial currents, with unknown consequences. Most of these are superstitions, as years of research in the Air Force and other services have shown. A major public education effort based on solid scientific and medical research, is needed to debunk the superstitions and identify and address the real risks.

4.Retail power beaming

Because SPG enables receivers to be set up anywhere, one obvious choice is to set up receivers at locations suitable for retail distribution by beamed power. The frequencies used for retail beaming can be very different from those used for the SPG itself, because the distances are much smaller, and the propagation may be through wet, low-level atmosphere. The issues in retail power beaming are discussed in a separate paper at this conference [27]

5. Integration with Utility-Scale Terrestrial Power

Summerer et al [28] have begun studies of how to optimize combinations of space and terrestrial power generation, and to use the global reach of SSP systems to link the European and Chinese markets. In the case of SPG, such integration is built-in, and essential to the system. Unlike GEO-based SSP systems, SPG receivers are much smaller, and easily integrated with any utility, solar or otherwise. It makes natural sense to co-locate solar collectors and converters with the SPG millimeter wave receivers.

6. Integration with micro renewable power systems

Given that receivers can be as small as a few meters, they can be co-located with other energy systems on a small scale, and use common storage and conversion equipment, improving cost efficiency. For example, millimeter wave receivers can be combined with terrestrial solar arrays on small farms or even in areas the size of a building roof or a parking lot. Such concepts of course require informed policy making.

7. Global energy market with real-time trading

The Space Power Grid involves real-time matching between fluctuating power demand and supply at numerous locations around the earth, with transmission delays on the order of 0.1 second. While the technology may be well in hand, the processes for real-time pricing, on a time scale much shorter than those of the present day grid, pose interesting problems.

8. Public Funding

The price of delivered power is 2 to 3 times that paid by US-based urban consumers, connected to one of the most efficient high-voltage transmissions grids in the world to nuclear plants that have already amortized their investments. There are several answers to this. The first is that initial markets for expensive beamed power will be in places where there is no electric power grid beyond the local area, where the competition is from imported fossil-based generators. A secondary market is to smoothen fluctuations in plant output, thereby obviating backup power generation. The marginal price for surge power and peak-demand power, is over 40 cents per KWH. So these initial prices are sustainable for a few years. Another obvious answer is that our baseline business case uses *no public funding*, other than the government support needed to obtain long-term funding. Trading off initial public funding versus return on investment later, runs into the policy issue of how to justify up-front public grants, along with levels of return that imply profit-making ownership.

That governments are willing to make the level of investment required for projects like the SPG, is shown by recent US initiatives. The US Department of Energy (USDOE) and ARPA-E have started research and development grant programs totaling several billion dollars per year related to transformational concepts (unfortunately the SPG is not yet among those).

8. Security Concerns

Last but by no means least, the SPG must pass security concerns. The USDOE is cited [29] as insisting that Smart Grid concept proposals in their new $3.9B R&D program, "prove" that they are taking steps to prevent cyber attacks. On the other hand, such programs will then generate the knowledge necessary to "prove" that the SPG can be effectively protected from such attacks. Since the Smart Grid must enable a large number of customers to connect and disconnect from the grid under computer control, often through the internet, it is feared that this opens vulnerabilities. Our take on this aspect is that it appears to be a move to shut down most of the security vulnerabilities and misconduct that now plague all internet usage.

Beyond the software vulnerabilities, the SPG will encounter serious security issues related to its power beaming levels and pointing technologies. Most space-related technologies are automatically classified under "dual-use" for export control purposes. In proposing the global space-infrastructure consortium in Ref. [26] we pointed out that such a consortium offered a way to address this issue. Security concerns today have changed very much from those prior to 2001. Today the focus is much more on keeping sensivitive technologies out of the hands of certain "non-state actors" so that blanket certifications based on citizenship are less relevant. These threats have resulted in even free democracies tolerating a level of intrusive information-gathering on individuals that would have been rejected just a few years back. Accordingly, this opens up a way to base admission to given technology areas based on careful vetting of individuals, regardless of their citizenship. A consortium modeled after the European Space Agency allows creation of separate facilities and project lines in each nation, within which qualified individuals can have access to a carefully delineated realm of technology and control systems. Policy-makers could focus on this concept to solve much of today's concerns and uncertainties that inhibit the competitiveness particularly of the US in space and energy technologies. Again, the European DC grid project [20] is an example of an international effort along these lines.

CONCLUSIONS

In this paper, the purpose, obstacles and issues in bringing space solar power to earth are discussed. The present congruence of international interest in renewable energy sources and in reducing greenhouse gas emissions, provide a window of opportunity to bring about Space Solar Power in synergy with the development of clean renewable power on earth. The policy initiatives advanced in Europe for comparable solar power grid project are discussed. The special features of the space power grid are presented, and shown to provide an excellent vehicle for global collaboration. While substantial technical challenges remain, it is shown that there are viable paths for these challenges, as well as for the economics and public/ international collaboration needed to make Space Solar Power available to humanity. The public policy initiatives needed for renewable energy, are seen to be acceptable in many nations. Security concerns that appear to pose formidable obstacles are cited as also posing unprecedented opportunities for wel-controlled collaboration between nations, through the participation of personnel who are cleared at the individual level, and through sequestering of technologies particular to the project as done in the European Space Agency's projects. The European TRANS-CP project is cited as a relevant current initiative to develop suitable policy.

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